Computing Observation Geometry for Small Satellites

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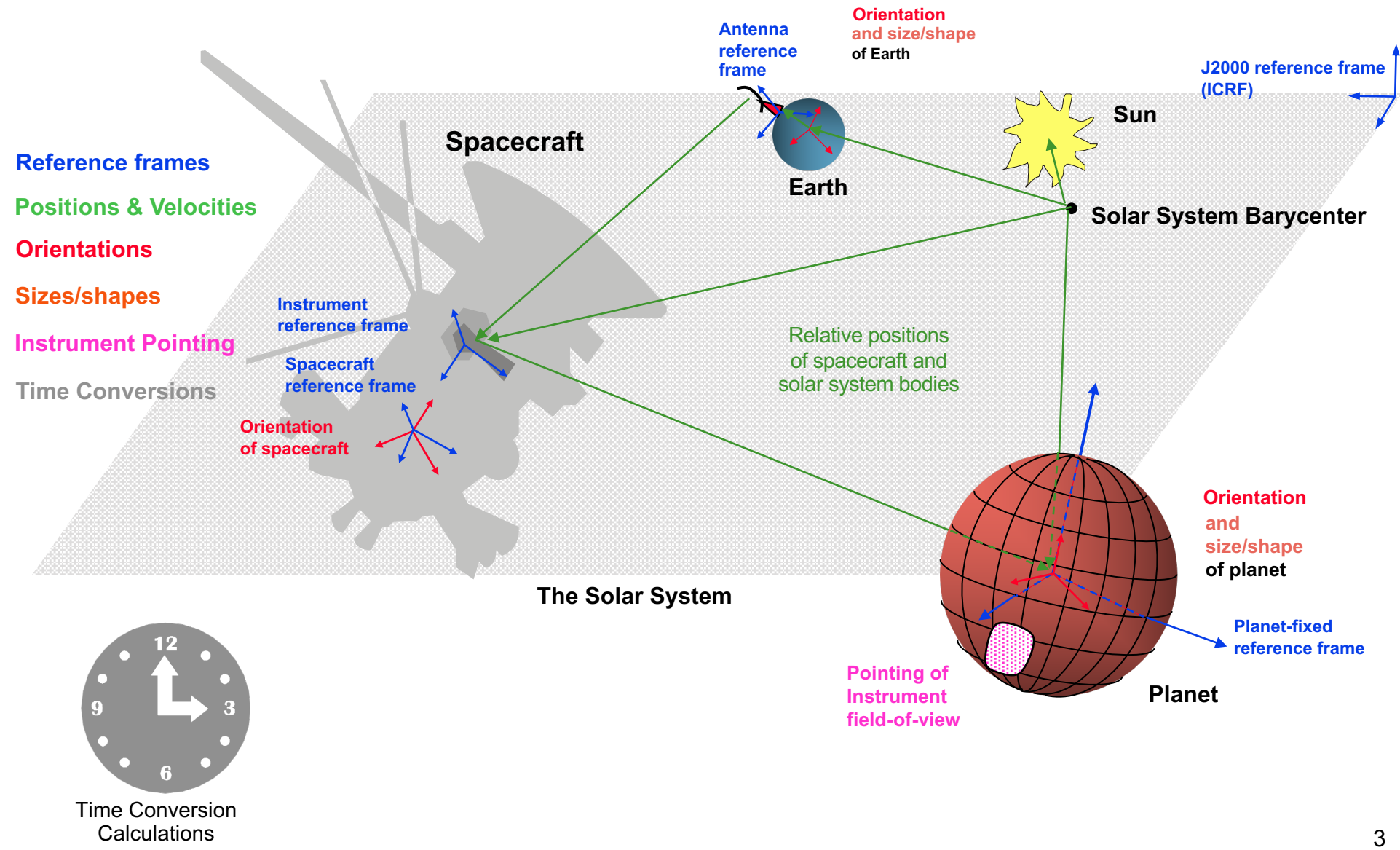
The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Topics

- What are “ancillary data?”
- Why are these data needed?
- Producing and using ancillary data using NASA’s “SPICE” system

A Pictorial of Ancillary Data



Examples of Using Ancillary Data

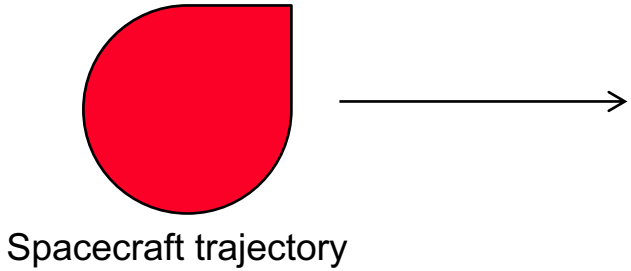
- **Help mission designers converge on a spacecraft trajectory design**

- **Compute observation geometry parameters needed by engineers for…**
  - **communications station view period calculations**
  - **antenna pointing**
  - **thermal and telecom analyses**

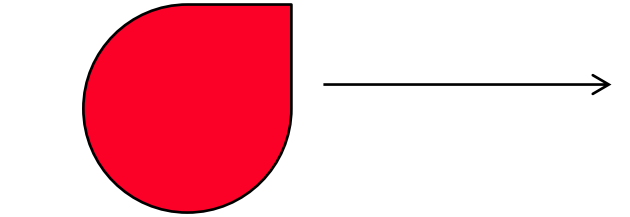
- **Compute observation geometry parameters needed by scientists for…**
  - **science observation planning**
  - **science archive preparation**
  - **science data analysis**

Contrast
"Ancillary Data" vs. "Observation Geometry"

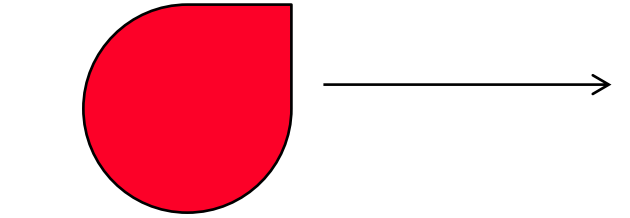
Ancillary Data
Files



Spacecraft trajectory



Spacecraft orientation



Spacecraft clock correlation

etc.

Some Software

Observation Geometry
Derived parameters

- Altitude = xxx km.
- Latitude = xxx deg.
- Longitude = xxx deg.
- Phase angle = xxx deg.
- etc.

Observation Geometry
Derived Conditions

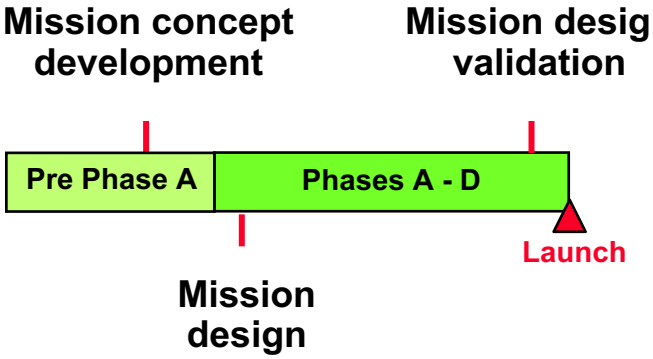
Within a defined time span:
- the spacecraft is occulted by Mars
- the altitude is at a global maximum
- the phase angle is in the range of 24 to 28 degrees
- etc.

When are Ancillary Data Used?

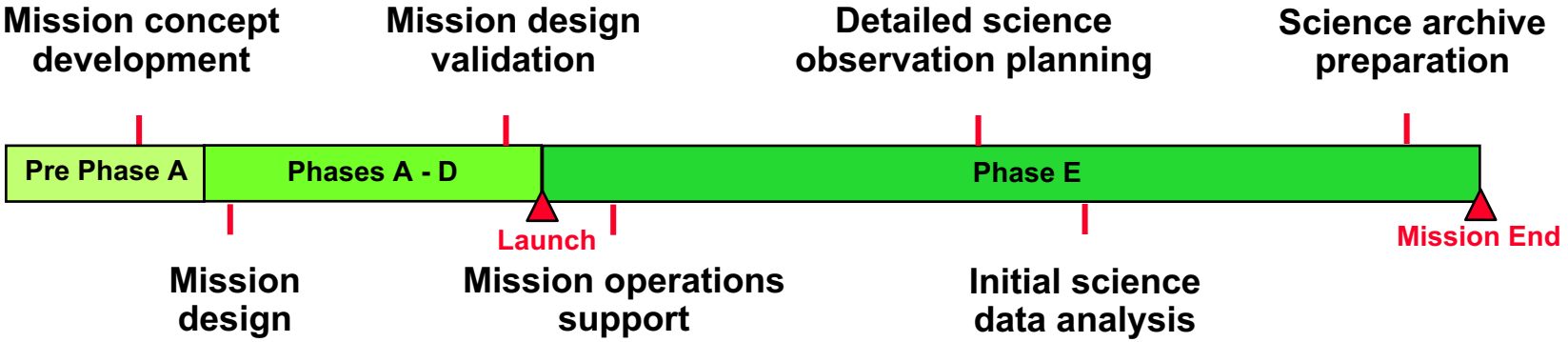
Mission concept development

Pre Phase A

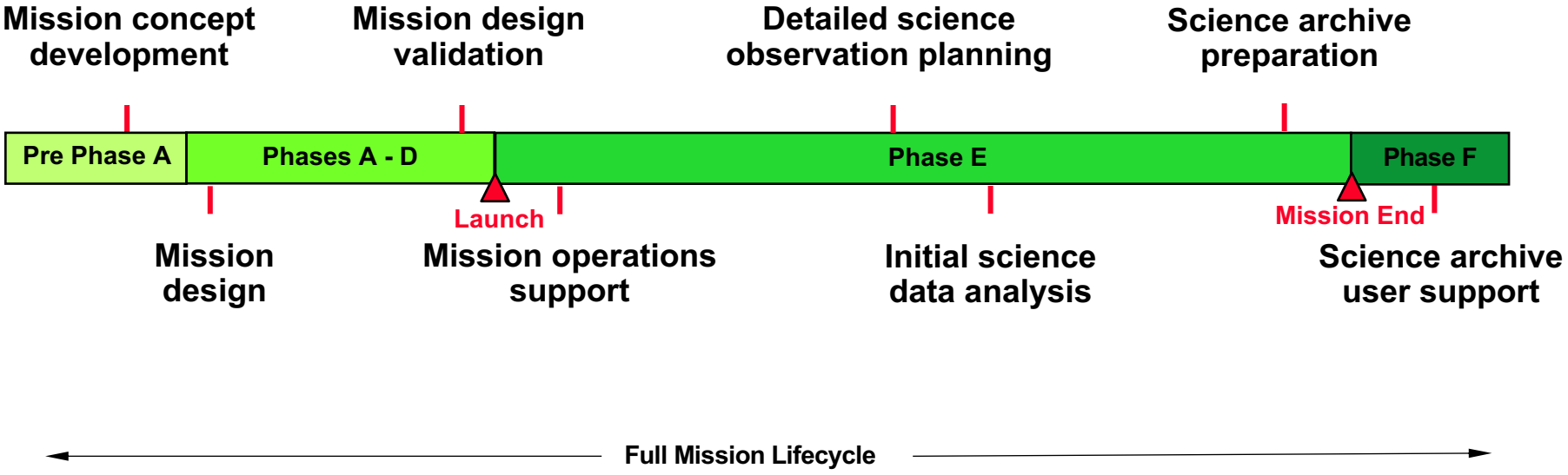
When are Ancillary Data Used?



When are Ancillary Data Used?



When are Ancillary Data Used?



Challenges in Producing and Using Planetary Ancillary Data

- Almost everything is moving and/or rotating
- Multiple reference frames, coordinate systems and time systems are used
- Size and shape estimates for target bodies are constantly evolving
- Improvements in spacecraft trajectory and orientation often occur during the mission

It's Your Choice

- **Within NASA, how your mission will deal with producing and using ancillary data is your choice–there are no NASA mandates re SPICE.**
  - **Not within the Planetary Science Division (PSD)**
  - **Probably not within other NASA divisions as well**
- **If your mission exists outside of NASA sponsorship, you still might find SPICE useful.**
- **The rest of this presentation describes SPICE in more detail.**

SPICE and NAIF

- **SPICE: stands for Spacecraft, Planet, Instrument, Camera-matrix, Events**
  - **SPICE is a system for providing scientists and engineers a wide assortment of space mission geometry**
  - **The SPICE concept was defined by a group of planetary scientists as one result of a 1983 NASA-mandated Planetary Data Workshop**
  - **The SPICE system is implemented by the NAIF group at JPL**

- **NAIF: Navigation and Ancillary Information Facility**
  - **Formed in 1983 at NASA's Jet Propulsion Laboratory**
  - **It's primary job is to develop the SPICE system**
    - » **For JPL and a few external missions, it also deploys and operates the SPICE system**
  - **It serves as the SPICE archive node of NASA's Planetary Data System**

SPICE System Components

Ancillary data files ("kernels")……

1100
1010
0101

Software (SPICE Toolkit) ……

Documentation ……

Tutorials ……

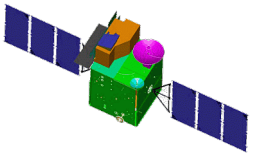
Programming lessons …..

Training classes ……

User consultation ……

From Where do SPICE Ancillary Data Come?

- From the spacecraft



- From the mission control center

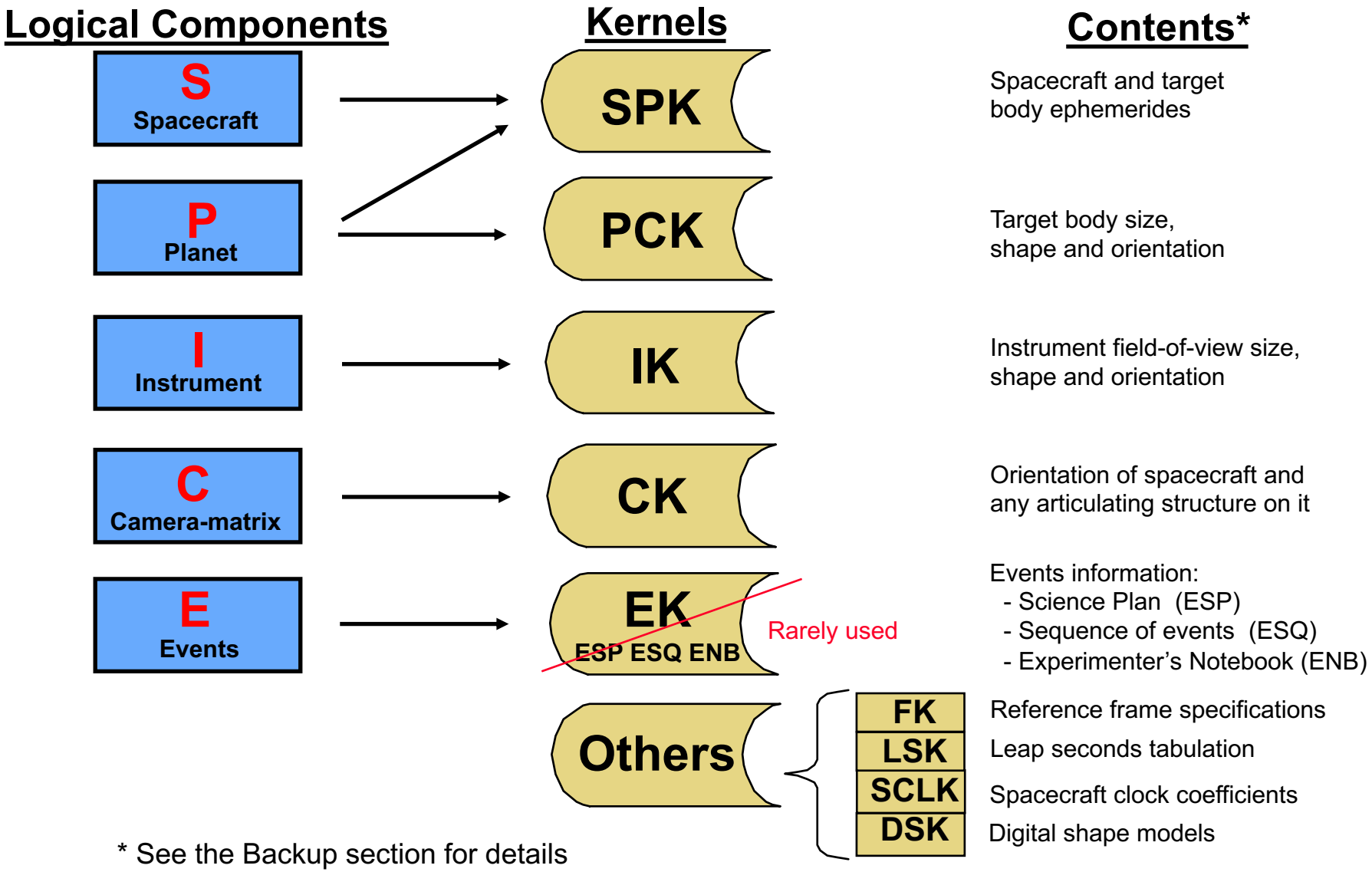
- From the spacecraft and instrument builders

- From science organizations

IAU

SPICE is used to organize and package these data in a collection of multi-mission ancillary data files, called "kernels."

SPICE-style Ancillary Data



* See the Backup section for details

SPICE Software
(The SPICE Toolkit)
https://naif.jpl.nasa.gov/naif/toolkit.html

Contents

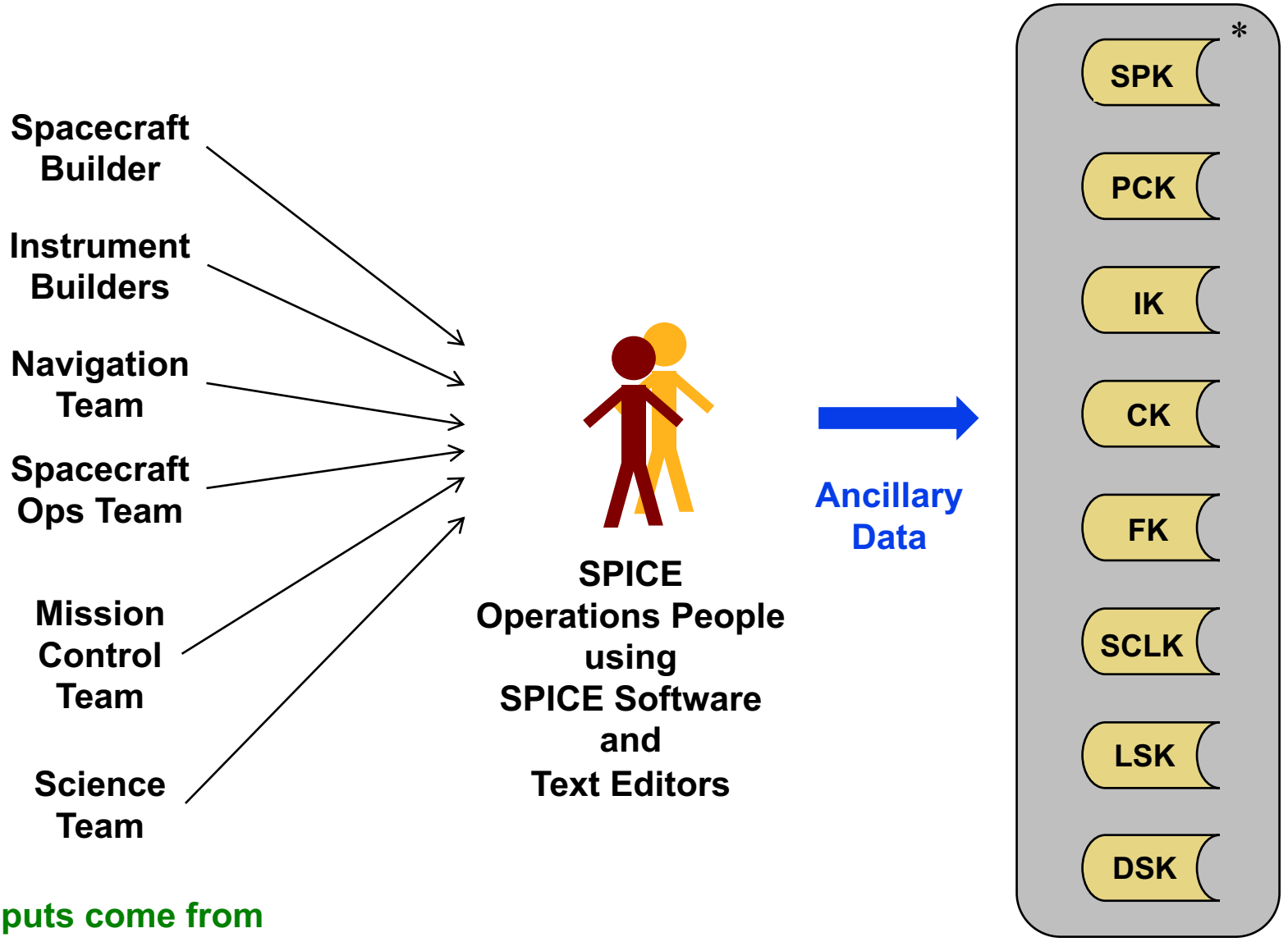
- **Library of subroutines (APIs)**
  - Typically just a few are used within a customer's program to compute observation geometry quantities derived from SPICE kernels
- **Utility Programs**
  - SPICE data production
  - SPICE data management
- **Documentation**
  - Highly annotated source code
  - Technical Reference Manuals
  - User Guides

Versions

- **Nine languages**
  - Fortran
  - C
  - IDL
  - MATLAB
  - Java Native Interface (JNI)
  - Python, Ruby, Swift, Julia (provided by 3rd parties)
- **Six platforms**
  - PC/Linux
  - PC/Windows
  - PC/CYGWIN
  - Sun/SPARC/Solaris
  - Sun/Intel
  - Mac/Intel/OSX
- **Several compilers**
  - For the Fortran and C Toolkits

All combinations provided by NAIF are fully built and individually tested before being made available to customers

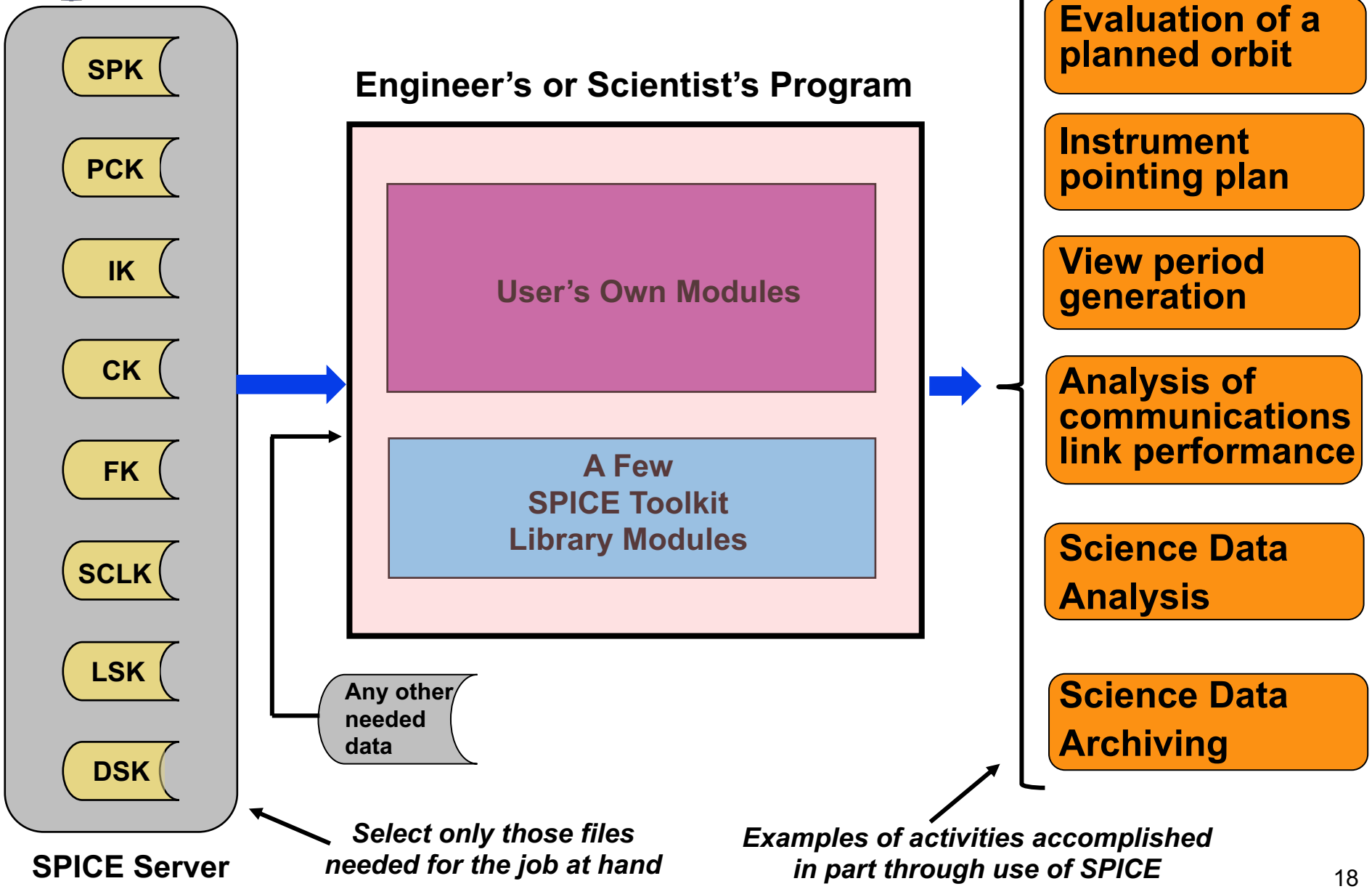
Producing SPICE Ancillary Data



Inputs come from multiple sources

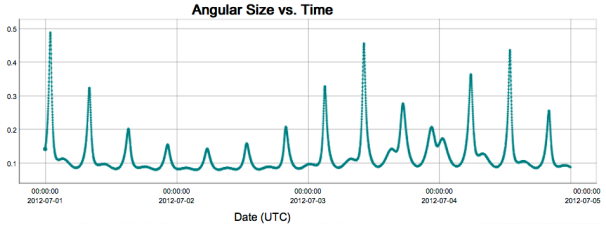
* See the Backup section for details

Using SPICE Ancillary Data



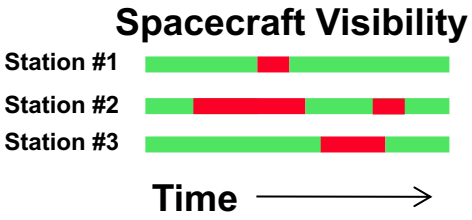
Typical Uses of SPICE

Evaluation of a planned trajectory

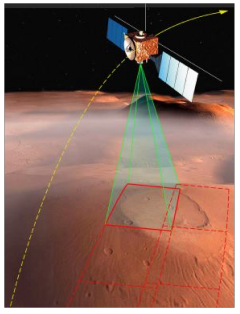


Angular size of Phobos as seen from the Mars Express spacecraft

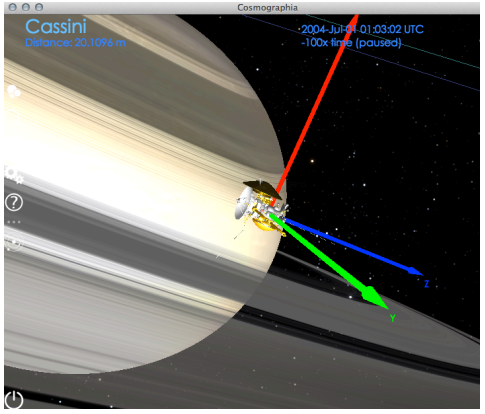
Mission engineering analyses



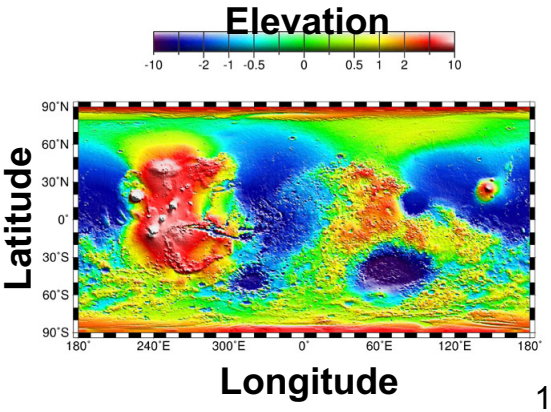
Planning an instrument timing and pointing profile



Observation geometry visualization

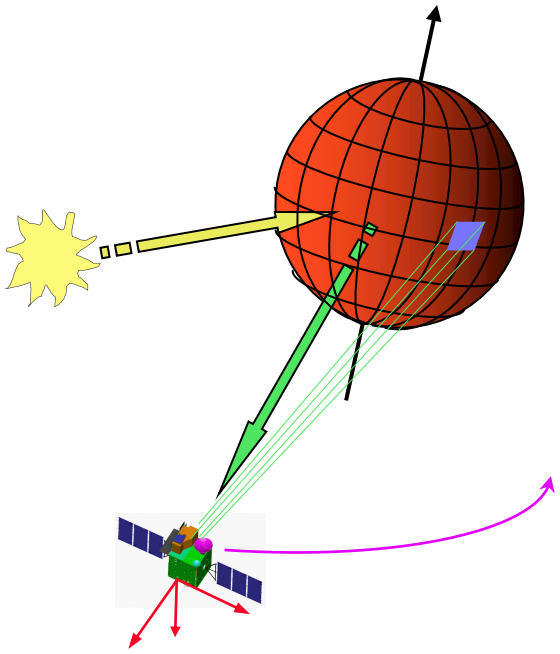


Science data archiving and analysis



Observation Geometry Computed Using SPICE - 1

Compute many kinds of derived parameters at selected times



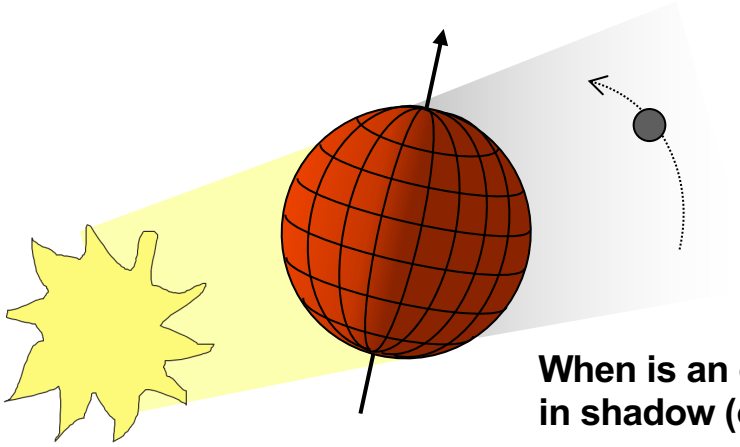
A Few Examples

- **Positions and velocities of planets, satellites, comets, asteroids and spacecraft**
- **Size, shape and orientation of planets, satellites, comets and asteroids**
- **Orientation of a spacecraft and its various moving structures**
- **Instrument field-of-view footprint on a planet's surface or atmosphere**

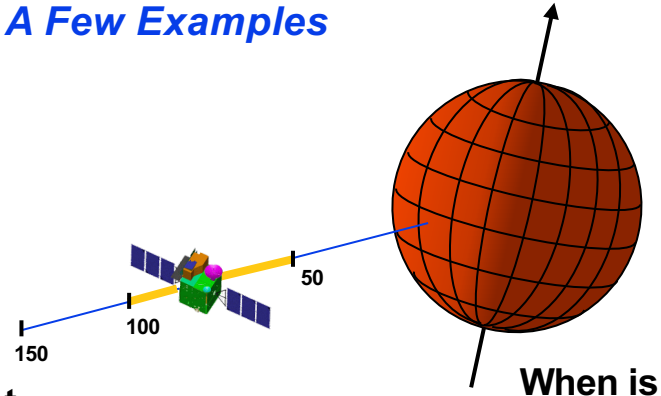
What One Can Do With SPICE

Find times when a specified "geometric event" occurs

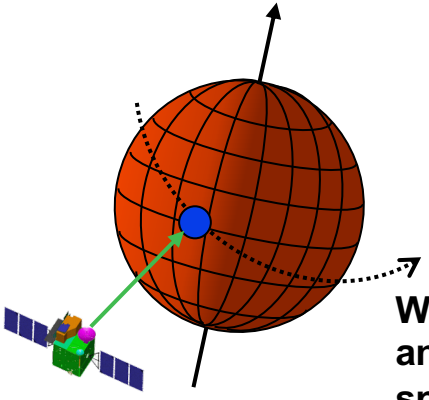
A Few Examples



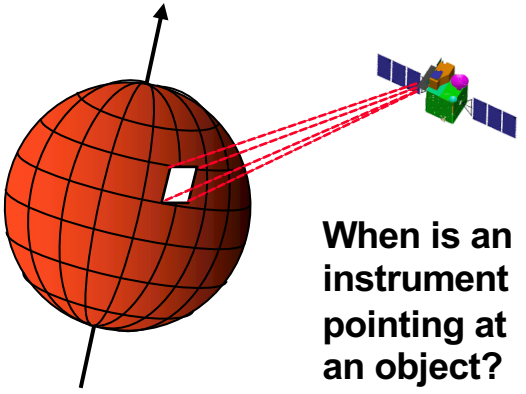
When is an object in shadow (occultation) ?



When is the spacecraft's altitude within a given range (say 50 to 100 km)?



When is an object in front of another, as seen from a spacecraft (transit)?



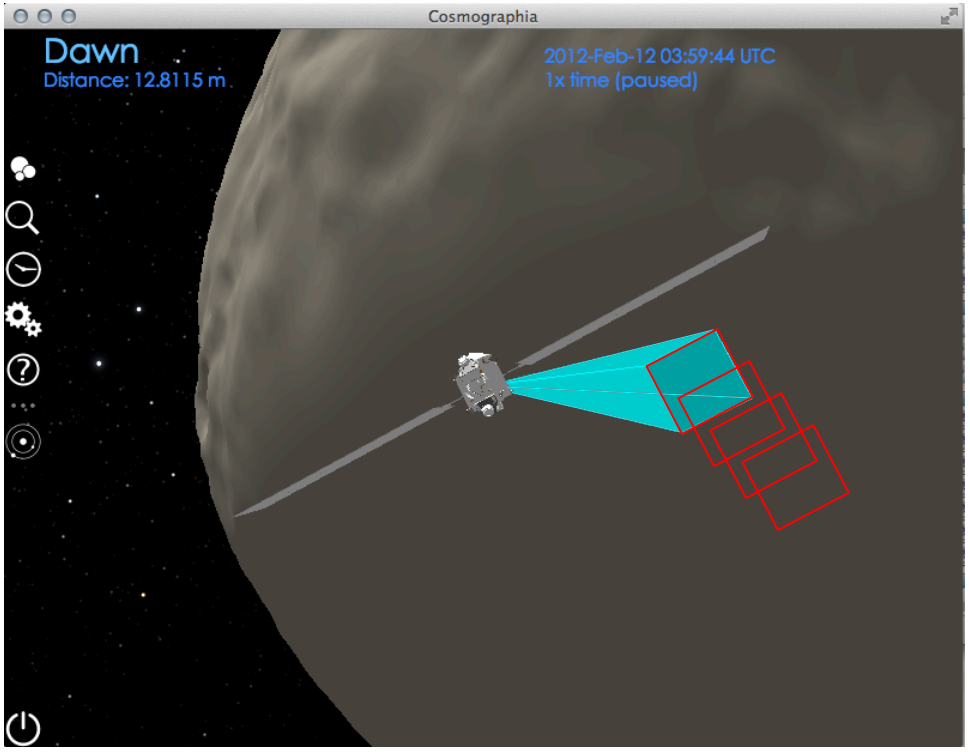
When is an instrument pointing at an object?

What Else Can One Do With SPICE?

Produce 3D Mission Visualizations

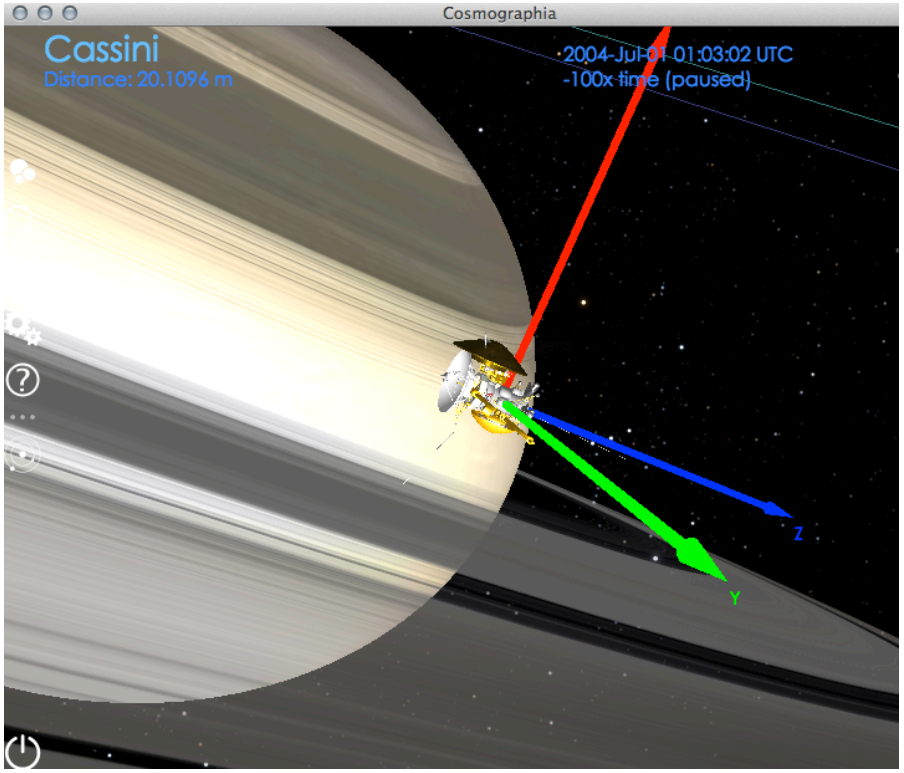
(Below we show only screen shots)

(See https://naif.jpl.nasa.gov/naif/cosmographia.html for details)



Cosmographia* visualization of DAWN's framing Camera photographing Vesta, including display of image footprints

Cosmographia* visualization of Cassini in Orbit at Saturn, showing spacecraft axes

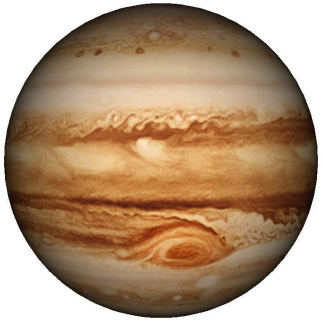


* SPICE-Enhanced Cosmographia is part of the SPICE tools suite

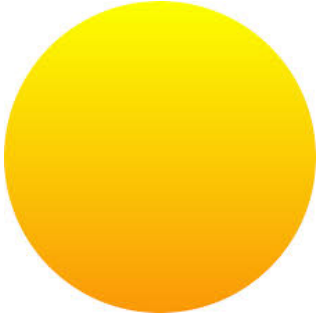
Kinds of Projects Using SPICE

- **Cruise/Flyby**
  - Remote sensing
  - In-situ measurement
  - Instrument calibration
- **Landers**
  - Remote sensing
  - In-situ measurements
  - Rover or balloon relay
- **Orbiters**
  - Remote sensing
  - In-situ measurement
  - Communications relay
- **Rovers**
  - Remote sensing
  - In-situ sensing
  - Local terrain characterization
- **Space Technology Demos**

  - e.g. optical communications



Planetary Science



Heliophysics

Earth Science

SPICE On-board?

- SPICE was not designed for on-board use, and NAIF has never promoted this application.
- Nevertheless, we've been made aware of three CubeSat missions that did have SPICE code on-board.
- Unfortunately all three spacecraft were lost before the use of SPICE would have been initiated.

Advantages of Using SPICE

- Provides lots of geometry computational capability
- Software is well tested and always backwards compatible
- SPICE is familiar to many scientists and engineers
- SPICE is the preferred ancillary data archive format:
  - for NASA's Planetary Science Division
  - for NASA's Planetary Data System
- No U.S. export restrictions
- No licensing

- SPICE components and generic data are free to all

Perhaps SPICE is not for Everyone

- Requires use of the SPICE software
  - Maybe your project doesn't wish to count on "outside" software?
- Learning to correctly *produce* SPICE data requires effort and at least some domain knowledge
- Learning to correctly *use* SPICE data and software also requires effort and domain knowledge
- SPICE doesn't specifically handle instrument geometric calibration
- Projects should provide SPICE-aware problem solving and user consultation services throughout the life of the mission

- Of course most of the issues mentioned above could apply to other approaches

Moving Forward

- **Whether you choose SPICE or another means for computing observation geometry, you should begin implementing your choice sooner rather than later**

- **NAIF encourages the CubeSat community to band together to lobby for institutional (NASA or otherwise) support; this could help you achieve the most timely and correct results, with the least risk and for the least expense**

What is Available from NAIF for Free?

- **The SPICE Toolkit, available at the NAIF website**
  - **Includes several SPICE kernel production utilities**
- **Access to all generic SPICE data available at the NAIF website**
  - **“Generic” kernels are data that are independent of any particular mission, such as planetary ephemerides**
  - **Some may be useful–even required–for your project**
- **A collection of SPICE tutorials and “open book” SPICE programming lessons, also available at the NAIF website**
- **About once every year and a half, a three day SPICE users training class**
  - **The next one is very soon – June 4-6, 2019 (Seats are still available)**
  - **See https://naif.jpl.nasa.gov/naif/WS2019_announcement.html to register**

What You'll Need to Provide if You Go It Alone Using SPICE

- Capable personnel who have learned how to produce and validate SPICE kernels
- A data production infrastructure for producing and distributing SPICE kernels
- Careful oversight of the SPICE kernel production process
- Any needed training for your scientists and engineers intending to consume your SPICE data
  - If the timing works out, perhaps they can attend the free SPICE training class mentioned on the previous page
- Consultation for your project's SPICE consumers
- Any SPICE data archiving required by your sponsor

What Could NAIF Provide if Funded to Do So?

- **If funded to do so, NAIF could provide some or all of:**
  - **SPICE data production**
  - **training and consultation for project SPICE users**
  - **archive production**
  - **training for others on SPICE data production or SPICE archive production**

- **What's the cost for such support?**
  - **There's not a simple answer, but for recent projects in which NAIF has a major role, NAIF ops support has ranged from about $30K to $70K per year.***
  - **The yearly cost typically varies depending on what effort is needed, how much of the mission is quiescent, and how long the mission will last.**

* These numbers are for illustrative purposes only and do not constitute a commitment on the part of JPL and/or Caltech.